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Hydrologic characteristics immediately after seasonal burning on introduced and native grasslands

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Abstract

Fire on rangelands used as a management tool or as an unwanted wildfire removes vegetation cover. Vegetation cover is thought to be a dominate factor controlling surface runoff and erosion. Vegetation removal by a burn should have an immediate effect on runoff and erosion. Surface runoff and sediment production were evaluated immediately after fall and spring season burns at 2 locations with different soil and vegetation types for 2 years in southeastern Arizona. The evaluations were conducted with a rainfall simulator at 2 precipitation intensities. Immediately after a burn there was not a significant change in runoff and erosion, therefore, vegetation cover by itself was concluded not to be a dominate factor controlling surface runoff and erosion. The increase found in surface runoff and sediment production from the burn plots was not significantly greater than the natural variability for the locations or seasons. Significantly higher surface runoff and sediment production was measured in the fall season compared to the spring at 1 location.

Key Words: surface runoff, erosion, rainfall simulator, vegetation cover, control burn, spatial variability

Prescribed burning is frequently used as a vegetation management tool on rangelands. The objectives are to: increase herbage yields, utilization and availability, improve wildlife habitat, control undesirable shrubs, prepare a mineral seedbed for grass establishment, and control various diseases (e.g., liver fluke and brownspot) (Wright 1974, Stoddart et al. 1975). The season of the burn influences the results and effectiveness of the burn treatment (Pase 1971, Pase and Knipe 1977, Whisenant et al. 1984, Cox 1988, Whisenant and Uresk 1990). These and other studies have been concerned primarily with changes in vegetation composition and not with potential changes in surface runoff and erosion.

Burning removes plant cover and leaves the surface soil unprotected to raindrop impact and may also produce hydrophobic substances that can reduce infiltration (DeBano et al. 1970, DeBano et al. 1976, Richardson and Hole 1978). Increases in runoff and erosion after burning have been reported (Wright et al. 1976, 1982). Most evaluations of the burn effect are commonly conducted with a double-ring infiltrometer or small sprinkler using a single intensity (Wood 1987, Knight et al. 1983, Roundy et al. 1978, Ueckert et al. 1978). These methods may be inadequate for 2 reasons. First, natural precipitation has variable intensity and distinct results may be obtained at different intensities, and second, significant spatial variability in infiltration (Merzougi and Gifford

1987, Devaurs and Gifford 1984). The results of a small simulator may be influenced by the spatial variability in infiltration. A large rainfall simulator would average spatial variability and allow for a more precise determination of a burn treatment effect.

Seasonal burning effects have been reported, with decreased infiltration from a late spring burn (McMurphy and Anderson 1965). Simanton and Renard (1982) showed seasonal differences in infiltration and runoff without burning. Further evaluation is needed on the interaction of seasonal burning and infiltration, surface runoff, and erosion.

Understanding changes in surface runoff and erosion caused by rangeland burns or seasonal influences is important for making range management decisions or modeling hydrologic responses. The premise has been that surface vegetation cover is a dominant factor controlling surface runoff and erosion. If vegetation cover by itself is a dominate factor controlling surface runoff and erosion, changes should be immediately evident after vegetation removal by a burn. The objective of this study was to evaluate the effect of vegetation removal by seasonal burning on surface runoff and erosion immediately after a burn on 2 vegetation and soil types.

Materials and Methods

Study Areas

The Santa Rita Experimental Range and Empire-Cienega Resource Conservation Area in southeastern Arizona were selected as study sites because of their different vegetation and soil types. Soil at the Santa Rita location is a White House gravelly loam (Fine, mixed, thermic Ustollic Haplargids) with 5 to 6% slope. The surface 10 cm of soil contained 1.0% organic matter, 17% rock fragments (>2 mm), and 68, 22, and 10% sand, silt, and clay, respectively, in the <2 mm fine earth fraction. Almost a pure stand of Lehmann lovegrass (*Eragrostis lehmanniana* Nees), an introduced species which is spreading over large areas of the Southwest (Cox and Ruyle 1986, Cox et al. 1989), covered the Santa Rita site and had not been grazed for a year prior to the study. Aboveground standing biomass on individual plots ranged from 2,200–5,900 kg/ha and litter from 600–2,900 kg/ha. Mean annual precipitation for the location is 423 mm with 60–70% as summer thunderstorms.

The soil at the Empire location is a Hathaway gravelly sandy loam (Loamy-skeletal, mixed, thermic Aridic Calciustolls) with 5 to 7% slope. The surface 10 cm contained 1.7% organic matter, 14% rock fragments, and 66, 22, and 12%, sand, silt, and clay, respectively, in the <2 mm fine earth fraction. The Empire site is dominated by native black grama [*Bouteloua eriopoda* (Torrey) Torrey], hairy grama (*Bouteloua hirsuta* Lagasca), and sideoats grama [*Bouteloua curtipendula* (Michaux) Torrey]. Individual plot aboveground standing biomass ranged from 700–4,200 kg/ha and litter from 120–900 kg/ha. The pasture had not been grazed for

1.5 years before the study. Mean annual precipitation at the location is 400 mm with 60–70% as summer thunderstorms.

Experimental Design and Data Analysis

Thirty-two 25 by 25-m plots, with two 3.05 by 10.66-m rainfall simulator subplots, were established at each location and fenced to exclude grazing. The treatments at each site were a burn and nonburn (control). Four blocks containing each treatment were established at the locations. Fall and spring seasons were evaluated with adjacent control and burn plots randomly selected within each block. The treatments were repeated for 2 years and at each location there were 4 control and burn plots used for each season and year.

The experimental design was a split plot with location as main plots. Subplots consisted of randomized complete block design with season by year factors in 4 blocks. The sub-subplot factor was treatment effect of burn vs control. Two subsample data values were obtained from each sub-subplot, providing a measure of sub-sampling error. Analysis of variance techniques were used to analyze the data. The subsample variance was found to be significantly less than the split error term. Therefore, the appropriate split plot error terms were used to test all effects. Main effects were either pooled or separated depending on the significance of the interactions ($P \leq 0.05$). Main effect means were separated with a least significant difference test (LSD).

Experimental Procedure

In the fall (October 1987–88) and spring (April 1988–89) for 2 years four 25 by 25-m plots at each location were burned starting with a back and finishing with a head fire. The prescribed burns were of low intensity and short duration that consumed the aboveground standing biomass to within 3–10 cm of the plant crowns and 90% of the litter.

Rainfall simulations were conducted at each location in the fall and spring seasons on 4 control and burn plots with a modified Swanson rotating boom simulator to allow 2 rainfall rates by controlling the number of open nozzles (Swanson 1965, Simanton et al. 1985). Rainfall was applied to the 2 rainfall simulator subplots at a rate of 55 mm/hr for 45 min and for 110 mm/hr for 15 min. Simulator energies were about 80% of natural rainfall (Simanton et al. 1985). The rainfall simulator intensities of 55 mm/hr for 45 min and 110 mm/hr for 15 min have been observed in the previous 13 years of Santa Rita location rainfall intensity data (unpublished data). Metal borders were inserted into the soil on top and sides to prevent inflow or outflow of surface runoff on the simulator subplots. At the bottom of the subplots a metal head wall and trough collected and directed surface runoff through a calibrated flume. Surface runoff rates were continuously recorded throughout each rainfall simulation event. The time runoff started after the start of rainfall was recorded. Runoff rates were integrated over the simulation event to calculate runoff volumes for the first 45 min, last 15 min, and total for the event. One liter runoff water and sediment samples were collected from the flumes at periodic intervals during each simulation event. Sampling intervals were dependent on changes in the runoff rate and ranged from 1 to 5 minutes with more frequent sampling during rapidly changing discharge rate. Runoff-sediment samples were weighted, allowed to settle, decanted, dried at 60° C, reweighed, and sediment concentrations calculated. The product of the discharge rate and sediment concentration was integrated to estimate sediment production for the first 45 min, last 15 min, and the total from each subplot.

Results and Discussion

There was no significant treatment effect or interaction between location, season, or year for surface runoff and sediment production for the first 45 min, last 15 min, the total event, or time of runoff as indicated by the analysis of variance even at a probability level of $P \leq 0.15$. Combining locations, seasons, and years and comparing control and burn means gave further evidence that immediately after treatment there was no detectable burn effect (Table 1). There was, however, a nonsignificant trend for increased

Table 1. Control and burn means for surface runoff, sediment production, and time to runoff from rainfall simulator events combining data from locations, seasons, and years.[1]

Treatment	Surface runoff	Sediment production	Time to runoff
	- - - - mm - - - -	- - - - kg/ha - - - -	- - - - min - - - -
		First 45 min.	
Control	1.91 (3.40)	25 (47)	15.2 (16.6)
Burn	2.28 (4.09)	34 (67)	14.5 (15.6)
		Last 15 min.	
Control	3.86 (4.41)	50 (56)	
Burn	4.74 (6.10)	72 (87)	
		Total	
Control	5.77 (7.50)	76 (98)	
Burn	7.01 (9.96)	106 (145)	

[1]Values in parenthesis are S.D.

surface runoff and sediment production and decreased time to runoff on the burn plots.

The burn treatment removed the standing biomass and litter cover to expose surface soil to raindrop impact energy. There was no effect of the vegetation removal by the burn treatment on surface runoff or erosion immediately after the burns. This agrees with other rainfall simulation studies which showed little differences in infiltration, runoff, and sediment production conducted on rangelands just after the standing biomass was removed by clipping (Johnson and Blackburn 1989, Simanton et al. 1991). The results of this study and others lead to the conclusion that aboveground standing biomass and litter by themselves are not a dominate factor controlling surface runoff and erosion in rangeland environments.

There have been studies on small burned watersheds averaging 45% slope that have shown increases in surface runoff that stabilized in 4 to 5 years on unseeded watersheds and in 1 to 2 years on seeded watersheds (Wright et al. 1976, 1982). Sediment production stablized when surface cover reached 53 to 72% depending on the precipitation for the year. Our rainfall simulations were conducted immediately after the burns and there could be a time factor involved before the treatment effect becomes detectable. In a pinyon-juniper woodland, infiltration evaluated on dry soil after a burn was similar to that on unburned areas (Roundy et al. 1987). One year later infiltration under shrub canopies tended to be lower and sediment production tended to increase with age of the burn. Ueckert et al. (1978) found a decrease in soil aggregate sizes after a burn. These effects persisted longer than 5 years. Thurow et al. (1986) suggested that the function of aboveground biomass is to protect the surface soil from the disaggregating effect of direct raindrop impact. Raindrop energy from postburn events can destroy soil aggregates at the surface and clog soil pores or form a crust that would restrict infiltration and enhance runoff and erosion (Smith et al. 1990). Rangeland soils with erosion pavement (surface gravel) protecting the surface and vegetation removed by clipping produced small changes in runoff and erosion with time (Simanton and Renard 1985). Erosion pavement was not on the soils in this study. The process of aggregate destruction and/or crust formation probably takes a number of events to complete and our evaluation was the first event, hence, the nonsignificant treat-

ment effect immediately after the burn.

The hypothesis that rainfall intensity could be important in determining a treatment effect was not confirmed by the results. The ratios of sediment production to runoff for the control and burn treatments were calculated from Table 1 to be 13 and 15 kg/ha/mm, respectively, and were the same for both rainfall intensities. This indicated a treatment responded the same irrespective of the rainfall intensity.

Studies in Utah have shown extreme spatial variability for infiltration on rangelands to a point that measurements taken on a 2-m grid interval have no correlation (Achouri and Gifford 1984, Merzougui and Gifford 1987). In New Mexico on a herbaceous dominated rangeland, 1 to 5 small plots (1-m²) were needed to achieve ±20% of the mean infiltration rate with 90% probability, but sediment production required up to 256 plots (Wood 1987). The rainfall simulator used in this study averaged small scale spatial variability over a large plot area plus the number of subplots would reduce larger scale spatial variability to a minimum. Therefore, spatial variability should not have prevented the determination of a treatment effect if it was greater than the natural variability.

Plots of runoff rates and sediment concentration vs time in Figures 1, 2, 3, and 4 illustrate spatial variability and the response to rainfall intensity. The runoff rates and sediment concentrations generally followed the same patterns with time on adjacent control and burn plots and subplots containing the same treatment. The exceptions were when there was runoff only on 1 treatment of the paired plots (Fig. 1) or large differences between subplots on the same treatment (Fig. 3). These differences were a measure of the
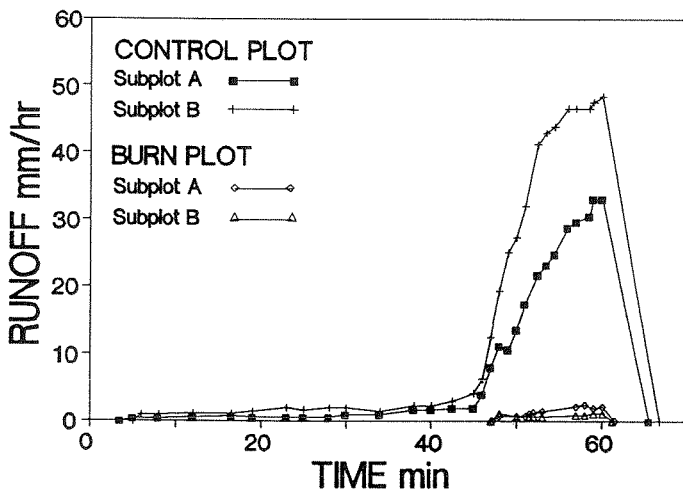

Fig. 1. Surface runoff rates vs time on a control and burn plot at the Santa Rita location.

natural variability in runoff and erosion and apparently not related to a treated effect. The response of runoff rates and sediment concentrations to rainfall intensity was further evidence of the absence of a treatment effect. The runoff rates changed with the changes in rainfall intensity and showed no preference with treatment. Sediment concentrations peaked on the treatments at the start of runoff and usually showed a second peak that was lower than the first when the precipitation intensity was increased. Sediment peaks almost always came before the runoff rate had reached equilibrium from the applied precipitation intensity (Figs. 2 & 4). Sediment concentration decreasing with time indicated there was a limited amount of soil available for transport. Even on the burn treatment, direct raindrop impact on the soil surface could not significantly increase the amount of soil dislodged and transported.

A significant season by location interaction was found for surface runoff and sediment production after combining treatments
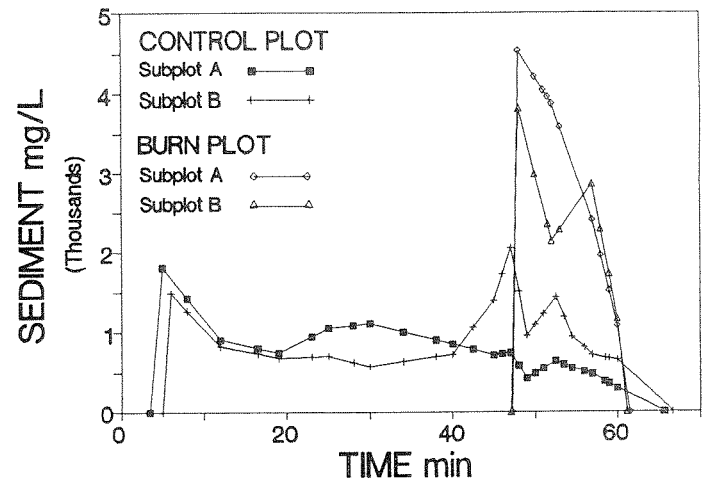

Fig. 2. Sediment concentrations vs time on a control and burn plot at the Santa Rita location.
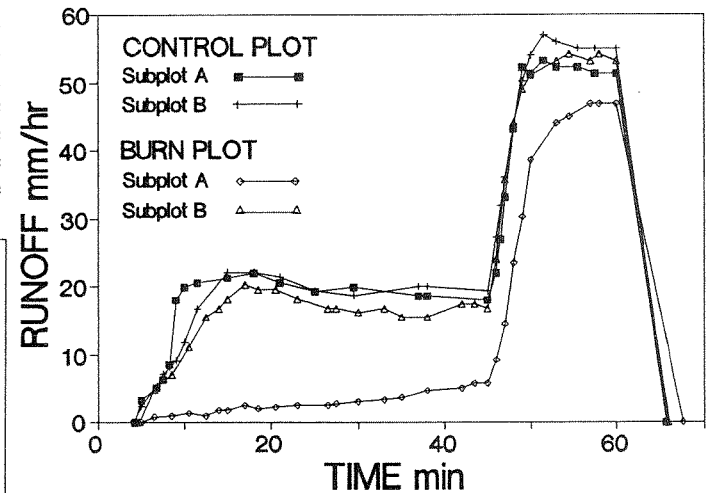

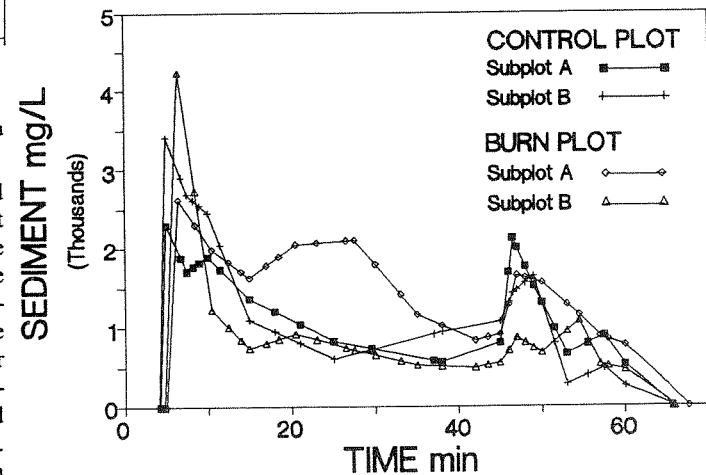Fig. 3. Surface runoff rates vs time on a control and burn plot at the Empire location.

Fig. 4. Sediment concentrations vs time on a control and burn plot at the Empire location.

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Table 2. Mean surface runoff and sediment production per rainfall simulator event by location and season combining treatment data.

Location	Season[1] Fall	Spring
	Runoff - - - - - - - - - - - - - - - mm - - - - - - - - - - - - - - -	
Santa Rita	1.91 a (2.74)	1.98 a (2.49)
Empire	16.6a (11.1)	6.3 b (6.8)
	Sediment - - - - - - - - - - - - - - kg/ha - - - - - - - - - - - - - -	
Santa Rita	25.6a (30.5)	31.5a (45.7)
Empire	222a (169)	98b (97)

[1]Within rows, data followed by different letters are significantly different LSD ($P<0.05$). Values in parenthesis are S.D.

(P = 0.05). Seasonal differences in runoff and sediment were not found at the Santa Rita location (Table 2). The amount of surface runoff was low and averaged about 3% of the applied precipitation. The Empire location had significantly greater runoff and sediment production in the fall. In the fall the runoff averaged 24% of the applied rainfall. These results on surface runoff support other studies that have shown the spring season to exhibit higher infiltration rates (Achouri and Gifford 1984, Schumm and Lusby 1963, Tricker 1981). The seasonal infiltration differences may be due to frost action and soil biological activity (Achouri and Gifford 1984, Simanton and Renard 1982, Gifford 1979). Detailed data on frost action or soil biological activity were not collected, but evidence of freeze-thaw activity was observed at the Empire location. The higher fall sediment production at the Empire location was attributed to the increase in runoff.

Summary and Conclusions

There was no significant burn treatment effect on surface runoff or sediment production as measured by rainfall simulator events immediately after treatment. Two different rainfall intensities on the bare soil of the burn treatment did not produce a significant increase in surface runoff or sediment production. These findings indicated that vegetation cover by itself is not the dominate factor controlling surface runoff and erosion at our study sites. Vegetation cover may interact with or influence other factors that are actually controlling surface runoff and erosion. The small increase in surface runoff and sediment production on the burn plots was within the natural variability of the 2 vegetation and soil types evaluated. A significant increase in surface runoff and sediment production in the fall compared to the spring season was found at 1 of the 2 locations.

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